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Reproduction and Stand Structure of Whitebark Pine in Relation to Fire and Sucession

by Penelope Morgan
Stephen C. Bunting

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FS Contact: Stephen Arno
UI Contact: Steve Bunting

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by
Penelope Morgan
and
Stephen C. Bunting

College of Forestry, Wildlife and Range Sciences
University of Idaho
Moscow, ID 83843

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INTRODUCTION

Whitebark pine (Pinus albicaulis), a subalpine white pine, is an important species in subalpine ecosystems throughout the northern Rockies, Sierra Nevada, and Cascade mountain ranges (Arno and Hoff 1989). Loope and Gruell (1973) found whitebark pine from 2400 to 3050 m in the Greater Yellowstone Area (GYA), often in nearly pure stands just below timberline. It is most common on thin soils of igneous origin (Harlow and Harrar 1969), but may occupy a wide variety of other soils (Weaver and Dale 1974). It may be small, scrubby, and multi-stemmed (Krummholz) near timberline or can attain commercial size and good form in mixed stands at lower elevations (Arno and Hoff 1989).

Whitebark pine is an early successional species in many habitat types (Steele and others 1983, 1981; Pfister and others 1977) and may occur in both pure and mixed stands (Arno and Hoff 1989). The stands tend to be open, with large whitebark pines often occurring in clumps (Weaver and Dale 1974). Stands may be even- or multi-aged. Whitebark pine occurred in 36 of 50 habitat types identified in eastern Idaho and western Wyoming by Steele and others (1983). Whitebark pine may occur as a seral stage dominant or in pure or mixed climax stands.

Whitebark pine is an important source of food for many wildlife species. Red squirrels (Tamiasciurus hudsonicus), grizzly bears (Ursus arctos var. horribilis), and Clark's nutcrackers (Nucifraga columbiana) are particularly dependent on the large, high-protein seeds produced by whitebark pine, but numerous other birds and rodents also eat the seeds (Hutchins 1990, Eggers 1986, Hutchins and Lanner 1982, Craighead and others 1982, Tomback 1982).

In substantial areas of the species' natural distribution, whitebark pine populations are declining in abundance (Arno 1986). Whitepine blister rust (Cronartium ribicola) has killed whitebark pine in many stands in the northern Rocky Mountains. Mountain pine beetle (Dendroctonus ponderosae) is by far the most damaging insect in mature stands of whitebark pine (Arno and Hoff 1989) and have greatly reduced populations in some areas. The insect usually only kills the larger trees because the inner bark thickness of smaller trees is not sufficient for the larvae to inhabit. Seral whitebark pine stands are being replaced by more shade-tolerant species, particularly subalpine fir (Abies lasiocarpa).

Fire may play an important ecological role in maintaining seral whitebark pine stands. Whitebark pine regeneration is favored in the open conditions created by high intensity, stand-replacing fires or other large-scale

disturbances, but little is known about the role of fire in the maintenance and management of the whitebark pine. Arno (1986) calculated a mean fire-free-interval (FFI) of 30 to 41 years with a range from 4 to 78 years for fires occurring in large stands (100-300 ha) in upper subalpine habitat types where whitebark pine is a seral species and replaced at climax by subalpine fir. Morgan and Bunting (1990) found the FFI in seral whitebark pine forests was less than 50 years during the pre-Euro-American period. For small areas less than 1 ha, Arno and Petersen (1983) found the mean FFI to vary between 72 and 94 years. Mattson and Reinhart (1990) estimated a FFI of 250 years for whitebark pine in the Mount Washburn area in Yellowstone National Park. Romme (1982) estimated a FFI of about 300 years for much of the lodgepole pine (Pinus contorta) forest of Yellowstone National Park. This interval may reflect conditions of the adjacent whitebark pine forests as well.

Whitebark pine is a pioneer on burns (Weaver and Dale 1974) and may dominate for 225 years or more (Loope and Gruell 1973). Whitebark pine trees grow slowly in both diameter and height (Weaver and Dale 1974). Although whitebark pine has thin bark, it often occurs on dry sites in open stands which reduces fire intensity and consequently, the tree's vulnerability to fire (Fischer and Clayton 1983). The common associates of whitebark pine are, in order of increasing fire resistance, subalpine fir, Engelmann spruce (Picea engelmannii), and lodgepole pine. Douglas-fir (Pseudotsuga menziesii) and aspen (Populus tremuloides) are relatively fire resistant and are occasionally associated with whitebark pine at its lower elevational limit. The most common associates in the GYA are subalpine fir and lodgepole pine.

More complete information on the whitebark pine ecosystem can be found in the recently published proceedings compiled by Schmidt and McDonald (1990) and a recent review of the species by Arno and Hoff (1989).

METHODS

The study was conducted in Yellowstone National Park and in the adjacent portions of the Shoshone and Bridger-Teton National Forests. Areas selected for sampling had whitebark pine trees present now or prior to the last stand-replacing fire and were classified as either an Abies lasiocarpa/Vaccinium scoparium (ABLA/VASC) or Abies lasiocarpa/Arnica cordifolia (ABLA/ARCO) habitat type (Steele and others 1983). These habitat types are 2 of the most common in which whitebark pine occurs in the GYA. Stands were chosen to represent a variety of ages since the last stand-replacing fire. Sites with known fire dates were located through the use of wildfire records. Additional

sites burned by older fires were located with the aid of aerial photographs. Additional sites that had not burned recently were located nearby. This resulted in clusters of sample sites being established. Clusters were located near Russell Peak and upper Jones Creek on the Shoshone National Forest, Gravel Lake and Togwotee Pass on the Bridger-Teton National Forest, and Dunraven Pass, Crow Creek Pass and Heart Lake in Yellowstone National Park. A total of 40 sites were sampled.

The size of the site sampled varied depending upon the density of the whitebark pine trees but most sites were from 15x20 to 20x20 m in size. All trees of every species with a height greater than 1.4 m were aged by collecting an increment core at this height. A subsample of trees were cored at both the base and 1.4 m to determine an adjustment, by species, for total age. All whitebark pine saplings (individuals 0.5-1.4 m in height) were also counted. A subsample of saplings was cored at the base or cross-sectioned to determine total age. All tree ages were converted to total age to allow analysis of stand dynamics. Five 2x20 m transects were randomly placed in the site parallel to the slope. The density of whitebark pine seedlings was determined within these transects. Conifer overstory coverage by species was also estimated for each site.

Each site was subjectively evaluated for fire hazard. Potential rate-of-spread, fire crowning, individual tree torching, fire intensity, resistance to control and overall fire hazard was rated as nil, low, moderate, high, or extreme as described by Fischer (1981).

The sites were classified into one of 4 successional stages based on the structure and the composition of the community. Classification relied primarily upon the development of the whitebark pine and subalpine fir populations in the stand. Stands consisting primarily of seedlings or young (<50 years of age) whitebark pine were classified as early seral. Those with mature whitebark pine and either seedlings or mature individuals of subalpine fir, but dominated by whitebark pine were classified as mid-seral. Stands composed of mostly subalpine fir but with many mature whitebark pine were classified as late mid-seral. Those stands in which the majority of trees in all age classes were subalpine fir were classified as late seral. Whitebark pine trees were often present in late seral stands, but they were often declining in vigor.

Cone production was assessed for each site. Four dominant trees were climbed and 5 cone bearing branches were cut from the tree. Cone bearing branches were normally found in the uppermost portion of the canopy except in the very open stands. In these stands cone bearing branches

were also found on the lower exterior branches of the canopy. Cone production was assessed by counting cone scars using the method of Weaver and Forcella (1985). This provided an index to the cone production within the 10 years prior to sampling.

An intensive fire history was developed for 8 mid-seral and 2 late-seral stands. Stands at the Russell Peak study area which is located within the Shoshone National Forest approximately 25 km northwest of Cody, Wyoming were sampled to develop this history. At 3 locations within a 100-ha sample area, cross-sections were collected from trees with multiple scars that appeared to be caused by fires. Grizzly bears and other animals may scar whitebark pines, but the scars can often be differentiated from fire scars by the presence of charcoal, which indicates a fire scar, or the presence of shredded bark or a nearby fallen tree which suggests that the scar was caused by something other than fire. All 3 locations had a minimum of 3 trees with multiple scars and were located near sample plots. Cross-sections were sent to the Laboratory of Tree Ring Research at the University of Arizona for analysis. Cross-sections were sanded and cross-dated using the skeleton plot technique (Swetnam and others 1985, Stokes and Smiley 1968). Based on characteristic cell structure, scars were classified as having high or medium probability of resulting from fires, or as scars probably created from other sources such a windthrow or black and grizzly bear feeding. Skeleton plots were made for each cross-section, and in some cases for 2 or more radii per tree. The skeleton plots were compared among the whitebark pine cross-sections and to 2 different tree-ring chronologies from the Yellowstone region, a Douglas-fir and limber pine (Pinus flexilis) series from Gardiner, Montana (Drew 1975). Unfortunately these chronologies did not cross-date satisfactorily with the whitebark pine specimens. However, cross-dating was observed on the skeleton plots among the whitebark pine cross-sections.

Fire scars were dated by their position within dated annual rings (Dieterich and Swetnam 1984, Arno and Sneck 1977). Relative positions of scars within annual rings were also noted where possible, so that inferences regarding seasonal timing of past fires might be made (Dieterich and Swetnam 1984, Barrett 1981). Many scars of varying severity were found on the cross-sections. Only those scars which had a high probability of being causedby fire were used to estimate the FFI. These scars were selected through inspection of the tree, the morphology and shape of the scar and subsequently developed woody tissue.

Data were analyzed graphically. All tree densities were expressed in per hectare values. Tables and additional figures summarizing results are presented in the appendix.

RESULTS

Our data show that most of the seral whitebark pine within the GYA regenerated 100 to 300 years ago and is presently declining in abundance. Subalpine fir dominates many sites and comprises the majority of the immature trees on many other sites. Lodgepole pine and Engelmann spruce are present in small amounts only and do not comprise more than 15% of the number of stems per ha in any stand we sampled. Within individual age groups of some stands, lodgepole pine and Engelmann spruce may be codominant with whitebark pine and subalpine fir. Including Engelmann spruce in the analysis further magnifies the trend of whitebark pine being replaced by shade-tolerant species.

Successional stages

Early seral stands (Fig. 1) were dominated by whitebark pine seedlings and saplings growing with a lush herbaceous understory. Subalpine fir seedlings were present in all of the early-seral stands we sampled. These stands were found only where large crown-consuming fires had occurred, as evidenced by the many standing dead snags or recently fallen logs of whitebark pine and subalpine fir. These stands were sampled within 15 years after fires occurred.

Mid-seral stands were dominated by whitebark pine, but subalpine fir saplings and mature trees were present (Fig. 2). These stands typically had dense, closed tree canopies with depauperate understories. On the ABLA/VASC ht, we found mid-seral stands where the last stand-replacing fire occurred 14 to 57 years ago. One of the mid-seral stands we sampled on the ABLA/VASC ht had survived a low intensity surface fire 14 years previously. On the ABLA/ARCO ht, in the mid-seral stands we sampled, it had been from 57 to 68 years since the last stand-replacing fire.

Late mid-seral stands were dominated by a mixture of mature subalpine fir and whitebark pine (Fig. 3). The oldest whitebark pine trees in these stands were older than those in mid-seral stands, and most of the subalpine fir trees were younger than most of the whitebark pine trees. The regeneration was clearly dominated by subalpine fir. On the ABLA/VASC ht, stand replacing fires had occurred as recently as 48 to 58 years, but in the ABLA/ARCO mid-seral stands, the last stand-replacing fire was at least 340 years ago.

Data from late seral stands on both habitat types reflect the dominance by subalpine fir in both the overstory and understory (Fig. 4). There are very few young whitebark pine stands, so the younger age classes are dominated by

subalpine fir. Although large, mature whitebark pine trees were present in all late seral stands, they were often declining in vigor. These stands predate the historic record of fire occurrence and although many of these stands contained evidence of low intensity surface fires, there was no evidence of a stand-replacing fire except in one late seral stand on the ABLA/ARCO site where a fire occurred in 1910.

In some cases, lodgepole pine and Engelmann spruce were present in the stand. When they did occur, they were similar in age to whitebark pine and subalpine fir, respectively.

Seedlings and saplings of whitebark pine were present in all seral stages. Sometimes the seedlings were abundant. However, we feel that it is unlikely that seedlings established under the closed canopy of mid-, late mid-, and late seral stands will grow into a codominant or dominant position in the tree canopy. The low ratio of sapling to seedling densities supports this conclusion (Table 1).

Because the classification of stands to successional stage was highly dependent on the presence of subalpine fir and whitebark pine, there was low correlation of successional stage and age since the last stand-replacing fire. Both subalpine fir and whitebark pine may establish soon after a fire, or it may take many years for a forest to develop. Many of the stands we sampled had also experienced low-intensity surface fire. For these reasons, successional development is not closely tied age of the stand.

Fire history

Whitebark pine frequently survives low-intensity surface fires. We found fire-scarred trees in virtually every stand we sampled and a number of whitebark pine trees had multiple scars. Low intensity surface fires favor whitebark pine over the less fire-tolerant subalpine fir.

Whitebark pine is also favored by high intensity fires which kill most of the trees in the stand. Whitebark pine established more quickly and in greater abundance than subalpine fir in the openings created by large, stand-replacing fires. According to the fire atlases of the Shoshone National Forest and Yellowstone National Park, high-intensity fires are much less common, but burn more area when they do occur. Data from Taylor (1974) also indicate that less than 1% of the fires occurring in Yellowstone National Park between 1930 and 1970 were greater than 400 ha but that these large fires included 93% of the total area burned during this period.

No scars of any origin found on whitebark pine trees dated after 1890 in the intensive fire history study near Russell Peak. This agrees closely with our scar data from the entire GYA. Only 1 scar was dated to be less than 100 years old that could not be attributed to a historic fire. Scars have become less common since 1850-1890. These data suggest that sources of scars, which include fires and grizzly bears, have been reduced since the late 1800's throughout the region. At that time, expanding settlement in western Wyoming probably resulted in more active and effective fire suppression, killing of grizzly bears and less frequent fires due to removal of the fine fuels by grazing. The American Indian was also displaced during this time period. The other possibility is that the region has undergone a slight climatic change that has made fires less likely to occur.

Fire and succession

Stand structure and composition were directly related to fire history in the intensively sampled Russell Peak area on the Shoshone National Forest. There, as in the entire region, whitebark pine is declining in abundance on both of the habitat types we sampled. This is apparently due to a decline in fire frequency.

Scars from 14 trees found within a 100 ha area in the general area of Russell Peak were dated. The FFI prior to 1875 was estimated to be 29 years, based on an average of all intervals between fires on individual cross-sections. The average FFI for the three groups of cross-sections varied from 13 to 46 years. Fire was relatively common within the Russell Peak area prior to 1875. The last fire that can be documented occurred in 1867.

The fire scar data indicate that in the Russell Peak region, fires were much more common from 1700 to 1850 than they have been since 1850. Over 40 probable fire scars formed during this period in the 14 whitebark pine sampled. Most of the fires were small as they scarred only one tree. There were, however, some years in which more than one tree was scarred in 2 or more of the 3 fire history data locations. When 2 or more scars were dated to the same year, it was assumed than the fire affected a larger area than when only one tree was fire-scarred. Our data indicate that such large fires occurred in 1595, 1672, 1693, 1721, 1810, 1825, 1836, 1848 and 1858. The average interval between these fires is 33 years with a range of 10 to 77 years. No such large-scale fire can be documented after 1858.

Even the more conservative 33 year FFI in the Russell

Peak region is extremely short for whitebark pine survival. Even if many mature whitebark pine trees survived the fires, it is doubtful that the species could persist with fires occurring so frequently. We are limited by having few trees dating prior to 1750 but it appears that fires were more frequent in the Russell Peak area between 1780 and 1850 than prior to 1780. The reasons for this are not evident but may be related to American Indian movements, climatic changes or random variation in natural ignition. The frequent fire occurrence between 1780 and 1850 significantly lowers the average FFI and may not reflect the long-term conditions under which the species existed in prehistoric periods.

Fires apparently occurred during different seasons of the year (Table 2). Fires were relatively evenly distributed throughout the growing season for whitebark pine. Large fires, those that scarred more than one tree, occurred more frequently late in the growing season or when whitebark pine was dormant. Thus, most fires that occur are small, burning only one or a few trees and they occur at any time during the growing season. Occasionally, such as in 1805, 1810, 1819, 1828, and 1858, large-scale fires apparently occurred in mid- to late summer or early fall. Multiple trees were scarred in 1810 and 1858, which suggests that late summer fires are often larger than early season fires.

Fire history and individual stand structure

The majority of the stands had significant amounts of subalpine fir regeneration. Stands 5 and 10 were typical (Figs. 5 and 6). These stands were classified as late mid-seral and late seral stands on the ABLA/ARCO ht.

In stand 5, almost all of the whitebark pine are over 150 years old and predate a series of fires that burned in the stand in the late 18th and early 19th century. Subalpine fir became established since the last fire which occurred in 1867. No fires can be documented in the stand after 1867. The canopy is now closed and few whitebark pine have established in the last 50 years, where an established conifer is defined as one greater than 1.5 m tall.

Stand 10 is a late seral stand. Again, most whitebark pine predate the period of frequent fires in the late 18th and early 19th centuries. Few whitebark pine have established in the last 200 years. Subalpine fir has regenerated in abundance in the last 130 years since the cessation of frequent fires in the area. In the absence of fires, advancing succession will lead to further decline in the abundance of whitebark pine in this stand.

Few trees in either stand established between 160 and

200 years ago, when fires were very frequent in the stand. Fires occurred 1789, 1794, 1798, 1805 and 1810. The short FFI during this period probably prevented most conifer regeneration on the site. The period between 1829 and 1845 also had a short FFI with the occurrence of 4 to 5 fires during this time.

Fire potential varies with successional stage

Overall fire hazard was highest in late seral stands and low to moderate for early, mid-, and late mid-seral stands (Table 3). Overall fire hazard rating integrates the potential fire intensity, rate of spread, torching, crowning, and resistance to control. However, the fire hazard was seldom rated higher than moderate in any of the stands we sampled. The higher fire hazard rating in late seral stands reflects the abundance of ladder fuels and the increasing tree crown density late in succession. Ladder fuels carry fire from the ground into the tree crowns and dense crowns fuel a crown fire under the right weather conditions (Lasko 1990). Ladder fuels and crown density both increase as subalpine fir becomes more abundant. The propensity for subalpine fir to produce fire brands when the live foliage burns increases the fire potential as that species becomes more prevalent.

Crowning potential, the likelihood that a fire will be stand-replacing when it occurs, is nil in early seral stands, low in mid-seral stands, and high in late mid-seral and late seral stands. Potential fire intensity follows similar trends. Ratings of potential rate of spread, intensity, torching, crowning, resistance to control, and overall fire hazard ratings are listed in tables in the appendix.

Stands are likely to burn only when they are very young, when there is sufficient fine fuel in the form of herbaceous understory vegetation, or late in the successional development when there is sufficient regeneration of subalpine fir and an accumulation of downed and dead woody fuel in the stand. Topography and structure of the adjacent stands is also important based on our limited field observations of areas that did and did not burn in 1988.

Cone production

Cone production varied between habitat types and between successional stages (Fig. 7). About twice as many cones are produced on the ABLA/ARCO habitat type as on the ABLA/VASC habitat type. The cone production index was generally higher for mid-seral and late mid-seral

successional stages, particularly in years in which the cone production was above average. During these successional stages, whitebark pine is relatively abundant. Few cones are produced in early successional stages. Whitebark pine grows slowly and may not start to produce cones until trees are at least 50 years old (Morgan and Bunting 1989), and most trees do not produce large numbers of seeds until at least age 70 to 100 years (Mattson and Jonkel 1990).

Where subalpine fir dominates in the late seral stands on the ABLA/VASC habitat type, cone production apparently declines despite the presence of healthy, mature whitebark pine. Perhaps this is due to the increased competition from subalpine fir. Mattson and Jonkel (1990) found heavy grizzly bear use in the ABLA/VASC ht in Yellowstone National Park. On the more productive ABLA/ARCO habitat type, the cone production index was highest in late mid-seral stands.

Cone production from stands of mixed tree species composition is apparently particularly important to grizzly bears (Reinhart and Mattson 1990). In stands where whitebark pine is seral and other conifers codominate, there is an alternative food supply. Squirrels can eat seeds of other conifers in years in which there are few whitebark pine cones produced. Since grizzly bears and many other wildlife species obtain their whitebark pine seeds from squirrel caches, a decline in cone production with advancing succession is significant.

While cone production within a stand and within a tree showed some periodicity, there was no consistent pattern of years in which very few or very many cones were produced. There is a noticeable decline in the cone production index in the year following abundant cone production (Fig. 8). Years in which cone production is high are most important to grizzly bears, for there is stiff competition for the seeds among other mammals and birds (Blanchard 1990).

SUMMARY AND CONCLUSIONS

Whitebark pine is seral to subalpine fir on ABLA/ARCO and ABLA/VASC habitat types. The absence of fire has resulted in an increase in the abundance of subalpine fir. In addition, existing whitebark pine produce fewer cones as the stand becomes dominated by subalpine fir and competition increases. If the current trend continues, whitebark pine will continue to decline in abundance and there will be fewer and fewer whitebark pine seeds available for wildlife food or for regeneration of new whitebark pine stands.

The likelihood of fire occurrence changes with the development of the forest stand. The probability of fire spread is initially high following high intensity fires due

to the increase in the herbaceous component of the plant community. Although whitebark pine regenerates readily following high-intensity, stand-replacing fires, the trees are not likely to survive subsequent fires that occur while they are still small and easily killed. As the stand develops, the likelihood of fire is reduced because the fine fuels are suppressed by the conifer overstory. During this period the probability of a high-intensity stand-replacing fire is low. However, low-intensity surface fires may occur. Fire likelihood and severity increases as subalpine fire becomes established in the stand, creating a fire ladder. Thus, the more advanced successional stages become susceptible to stand-replacing fires.

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FIGURE AND TABLE TITLES

Figure 1.--Stand composition (Mean number stems/ha) for early seral stands on the Abies lasiocarpa/Vaccinium scoparium (ABLA/VASC) habitat type.

Figure 2.--Stand composition (Mean number stems/ha) for mid-seral stands on the Abies lasiocarpa/Arnica cordifolia (ABLA/ARCO) and Abies lasiocarpa/Vaccinium scoparium (ABLA/VASC) habitat types.

Figure 3.--Stand composition (Mean number stems/ha) for late mid-seral stands on the Abies lasiocarpa/Arnica cordifolia (ABLA/ARCO) and Abies lasiocarpa/Vaccinium scoparium (ABLA/VASC) habitat types.

Figure 4.--Stand composition (Mean number stems/ha) for late seral stands on the Abies lasiocarpa/Arnica cordifolia (ABLA/ARC)O and Abies lasiocarpa/Vaccinium scoparium (ABLA/VASC) habitat types.

Figure 5.--Composition (Number stems/ha) of stand 5, a typical mid-seral stand on the Abies lasiocarpa/Arnica cordifolia (ABLA/ARCO) habitat type, Shoshone National Forest, Wyoming.

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Figure 1

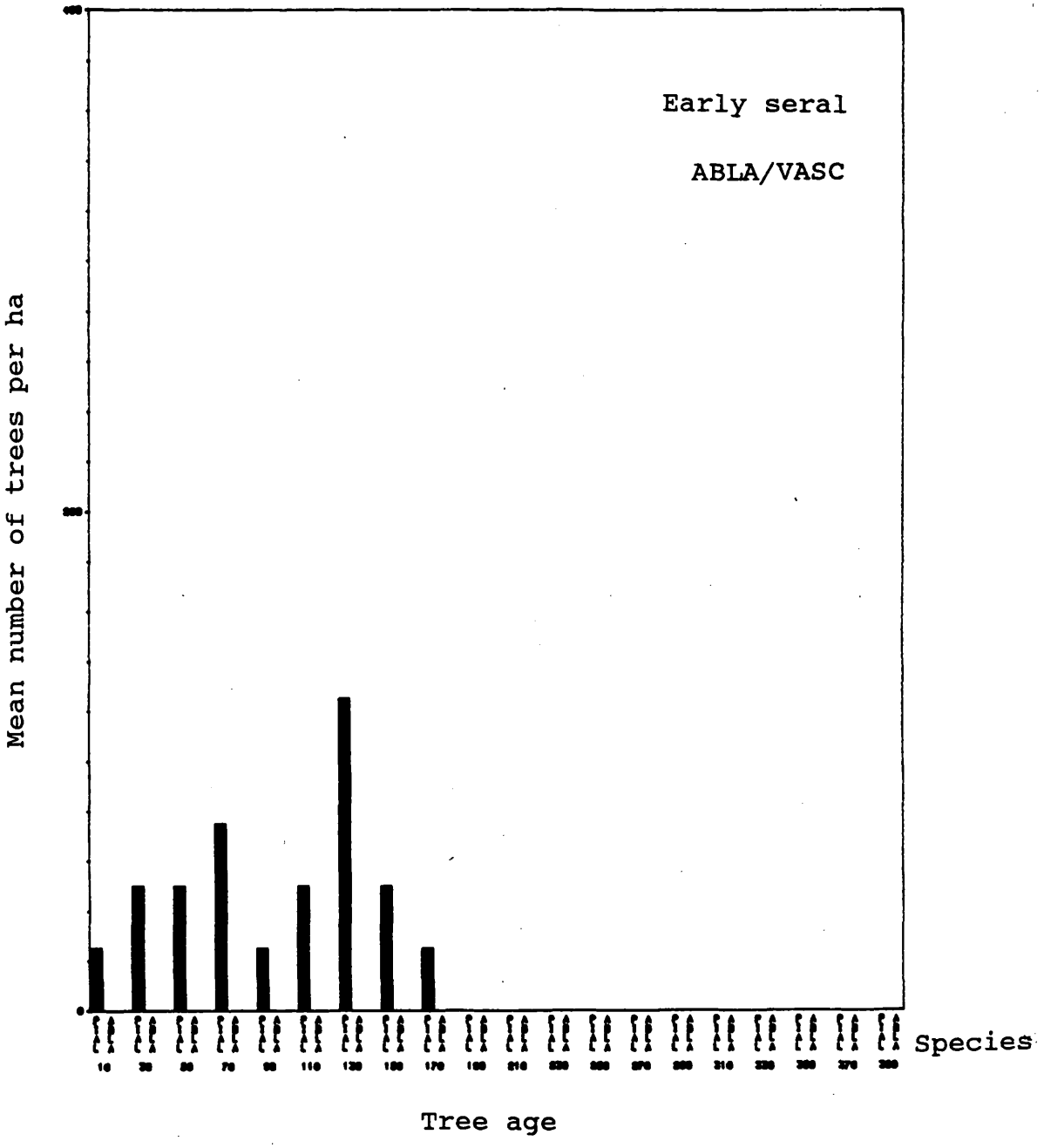

Early seral
ABLA/VASC
Mean number of trees per ha
Species
Tree age

Figure 2

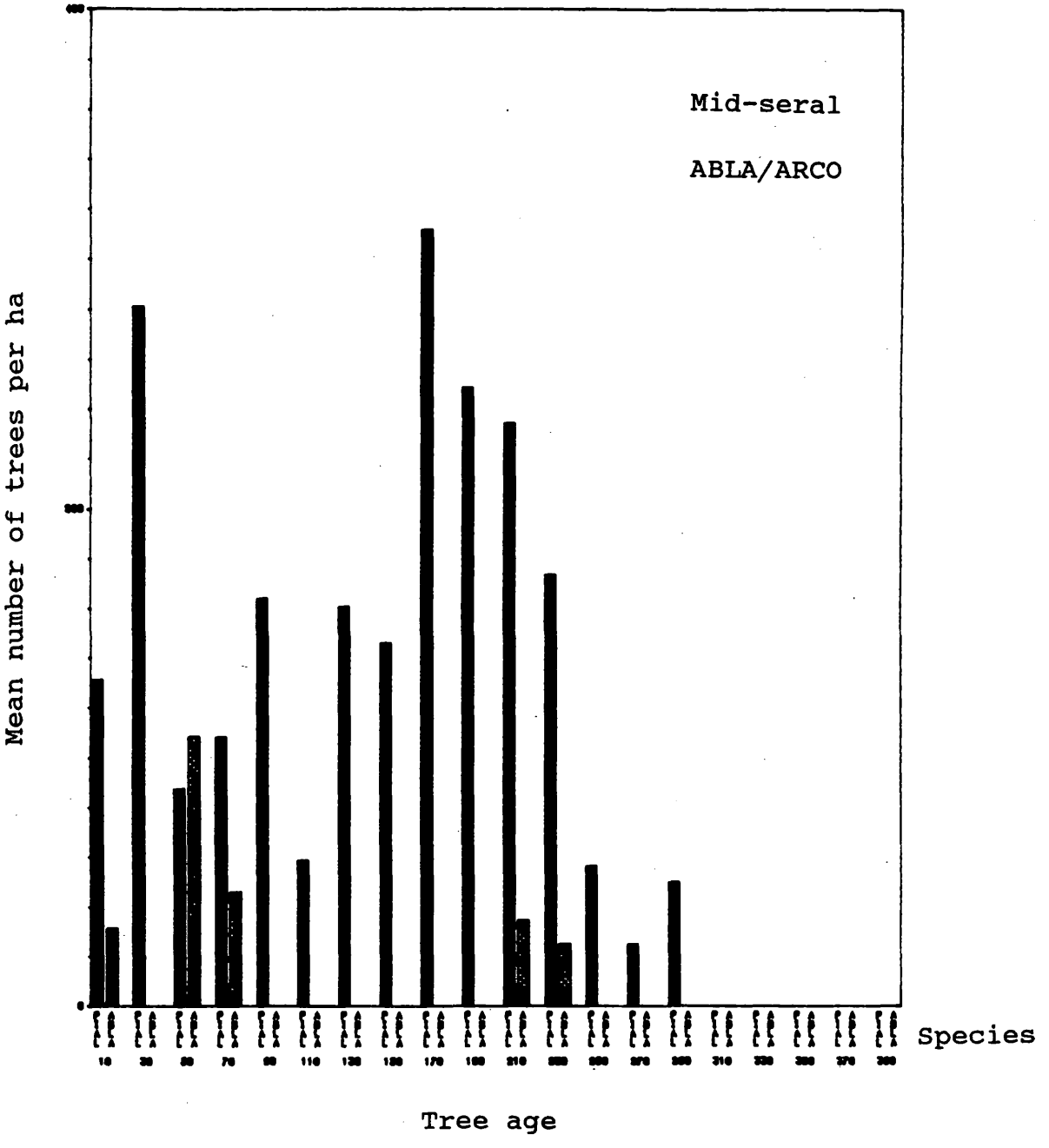
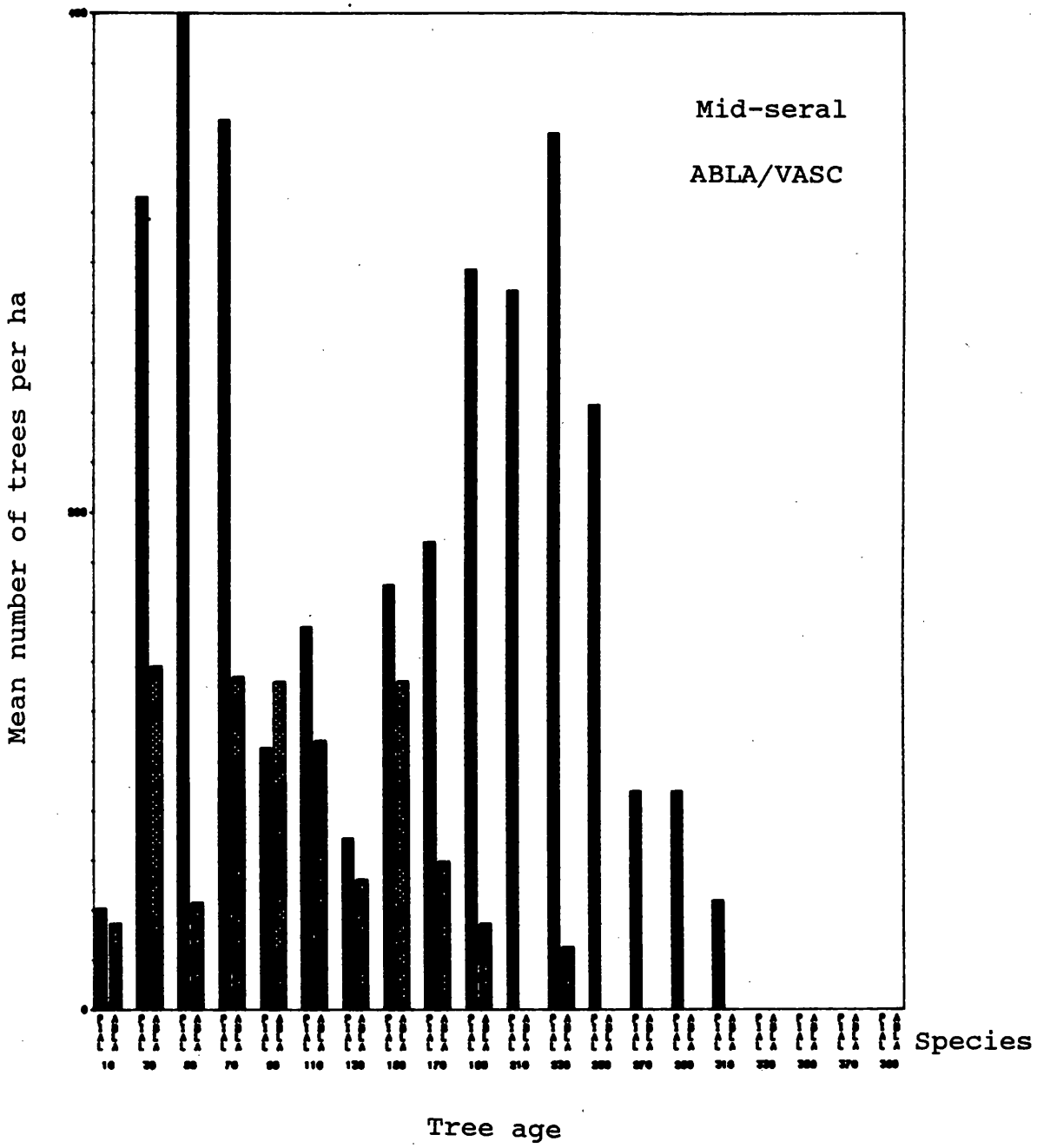
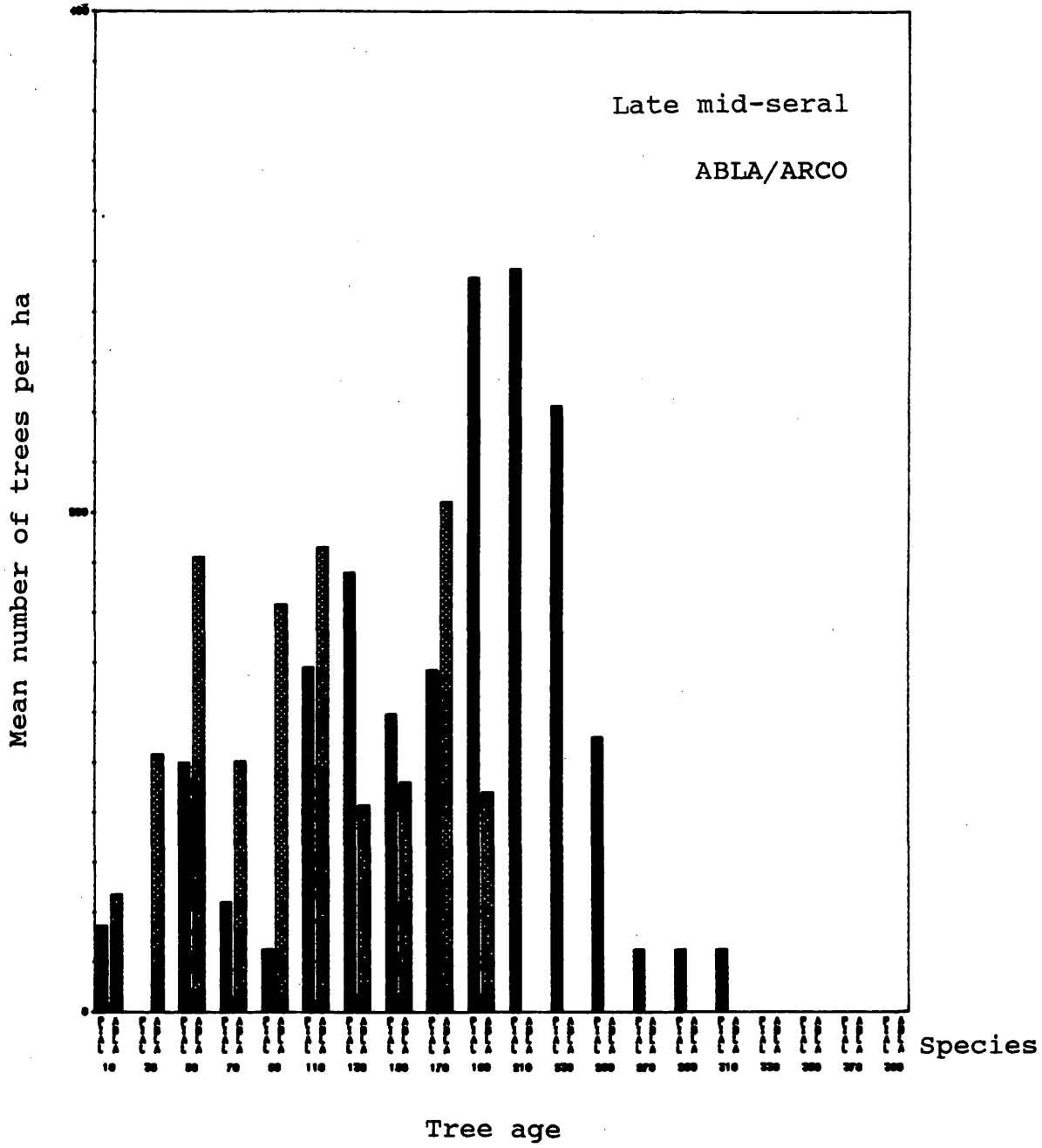
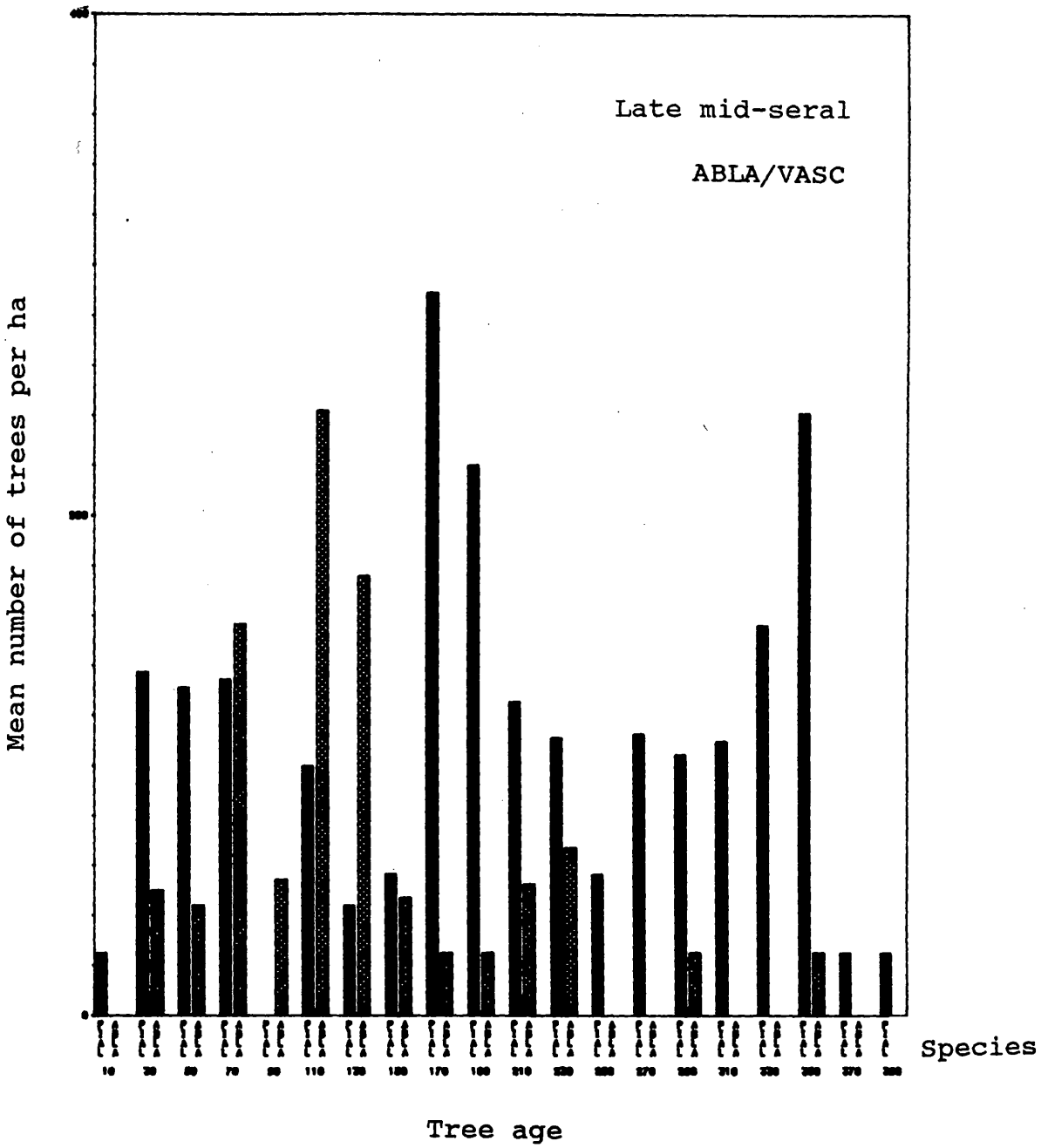

Mid-seral
ABLA/ARCO
Mean number of trees per ha
Species
Tree age

Figure 2


Mid-seral
ABLA/VASC
Mean number of trees per ha
Species
Tree age


Late mid-seral
ABLA/ARCO
Mean number of trees per ha
Species
Tree age


Late mid-seral
ABLA/VASC
Mean number of trees per ha
Species
Tree age

54

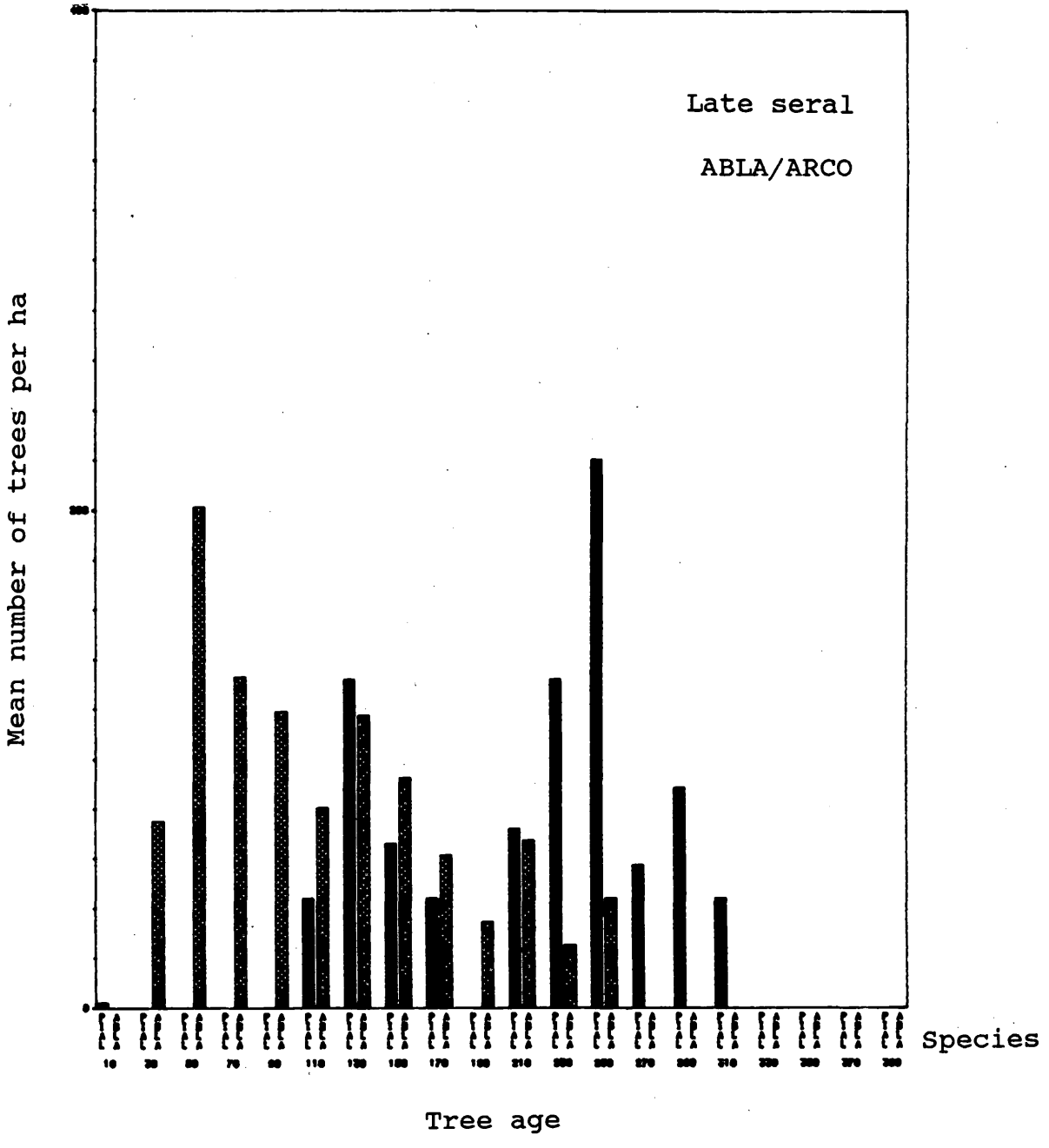

Late seral
ABLA/ARCO
Mean number of trees per ha
Species
Tree age

fig. 4

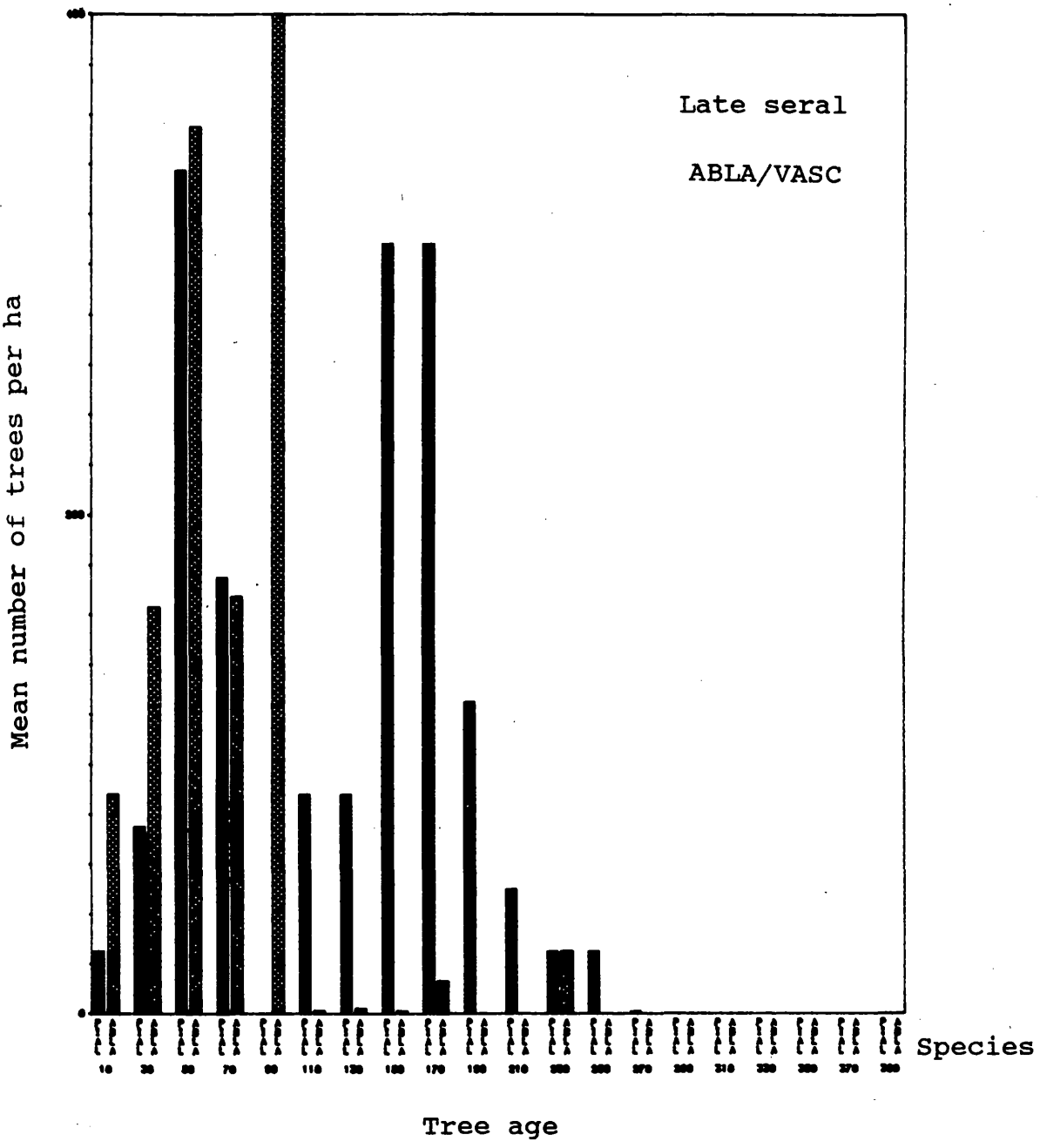
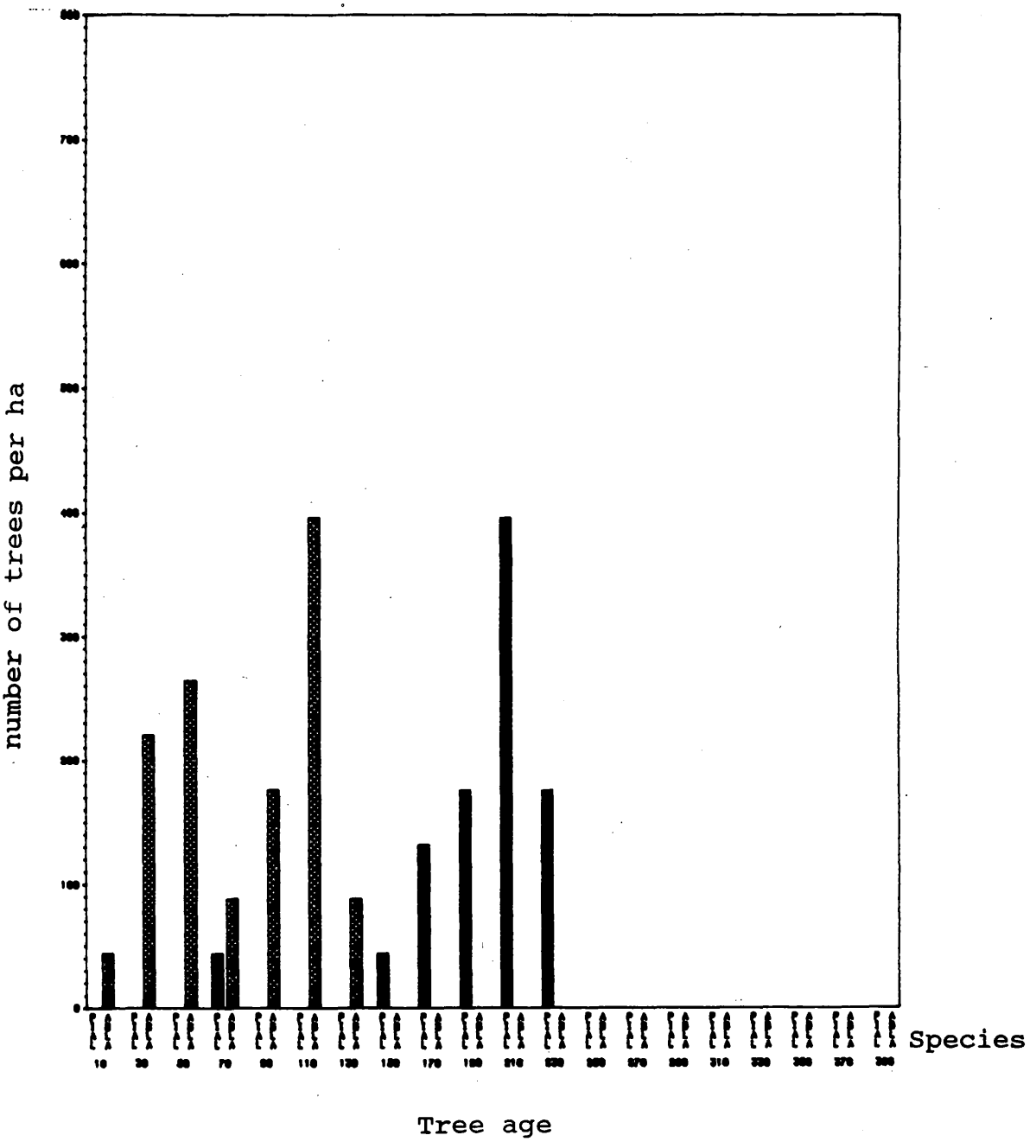
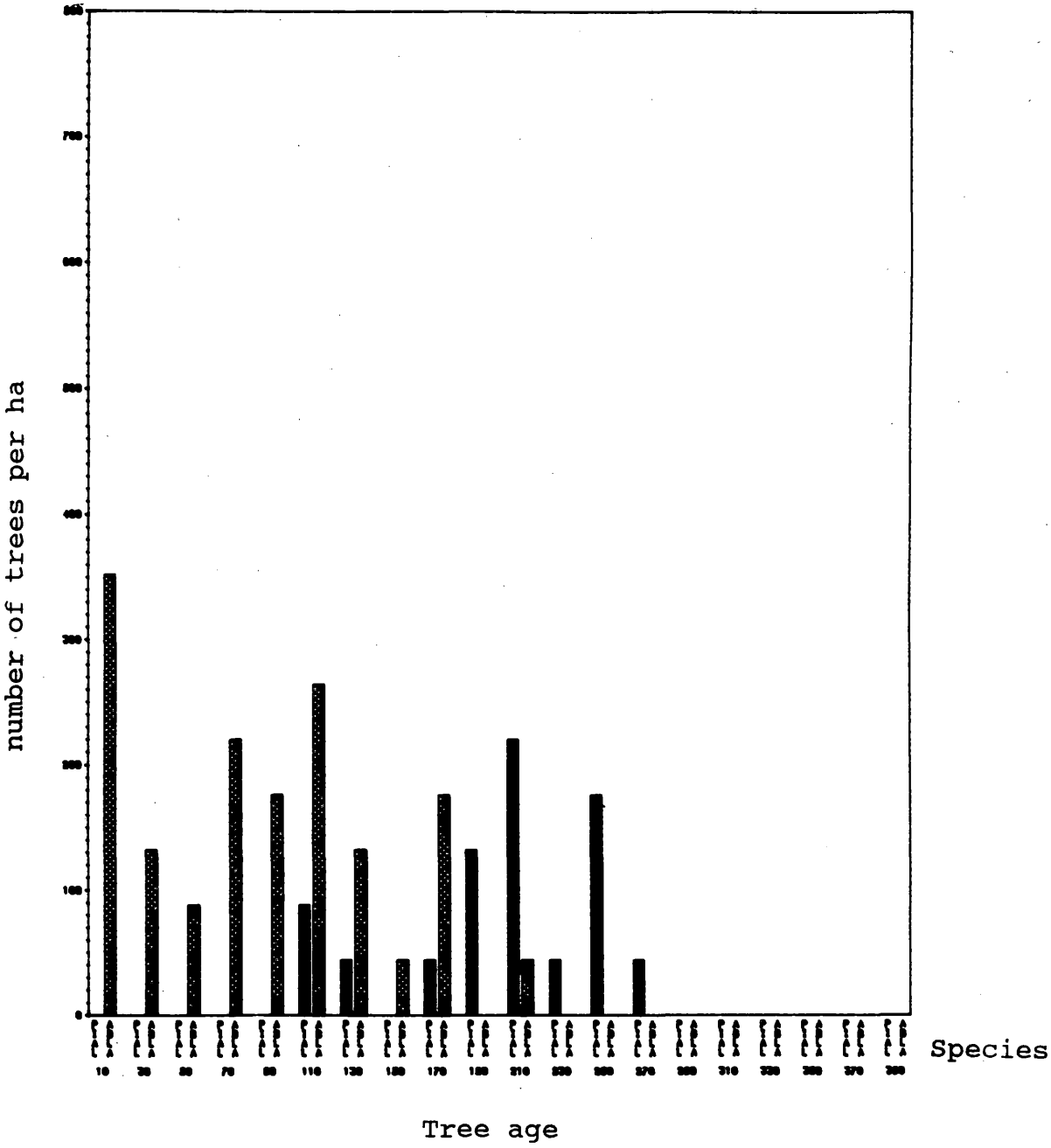
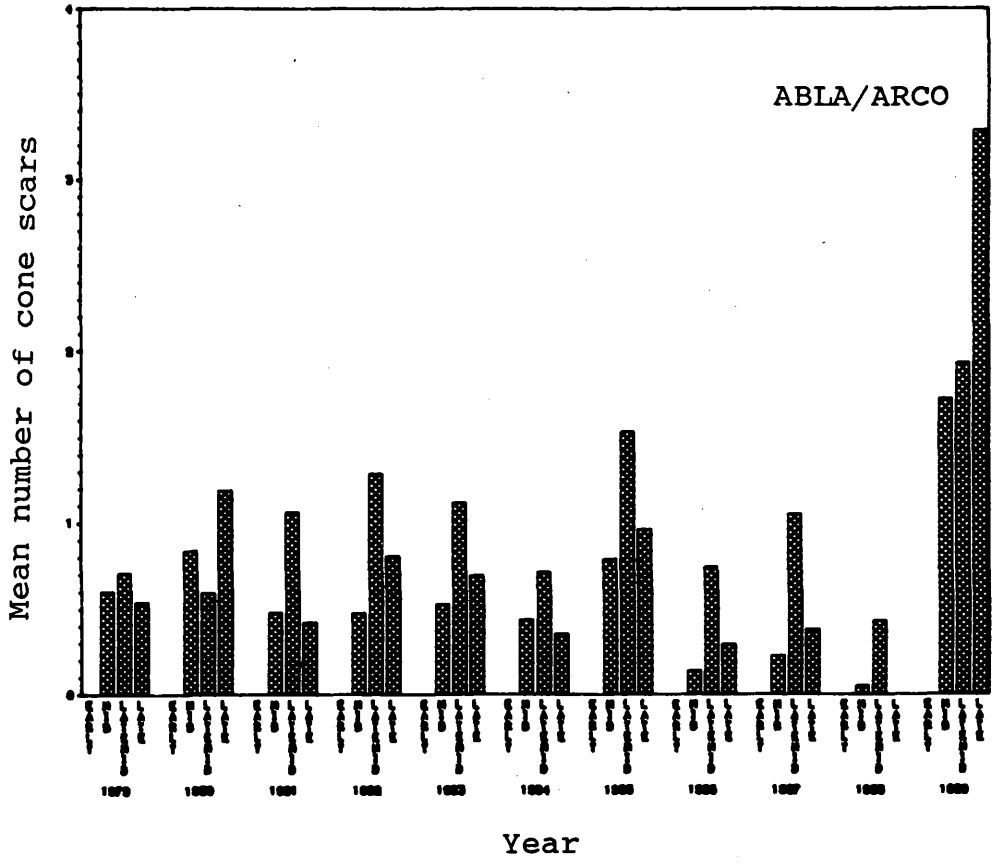

Late seral
ABLA/VASC
Mean number of trees per ha
Species
Tree age

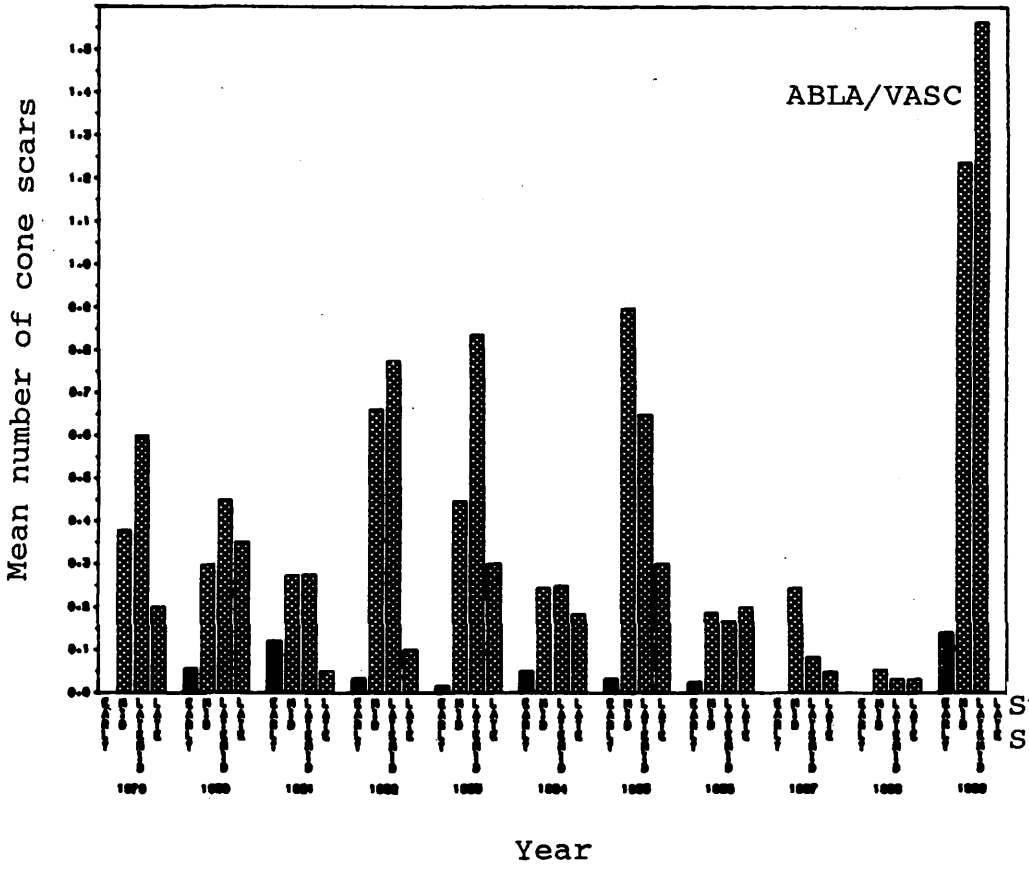
Fig 5. Stand S-5



6 S-10

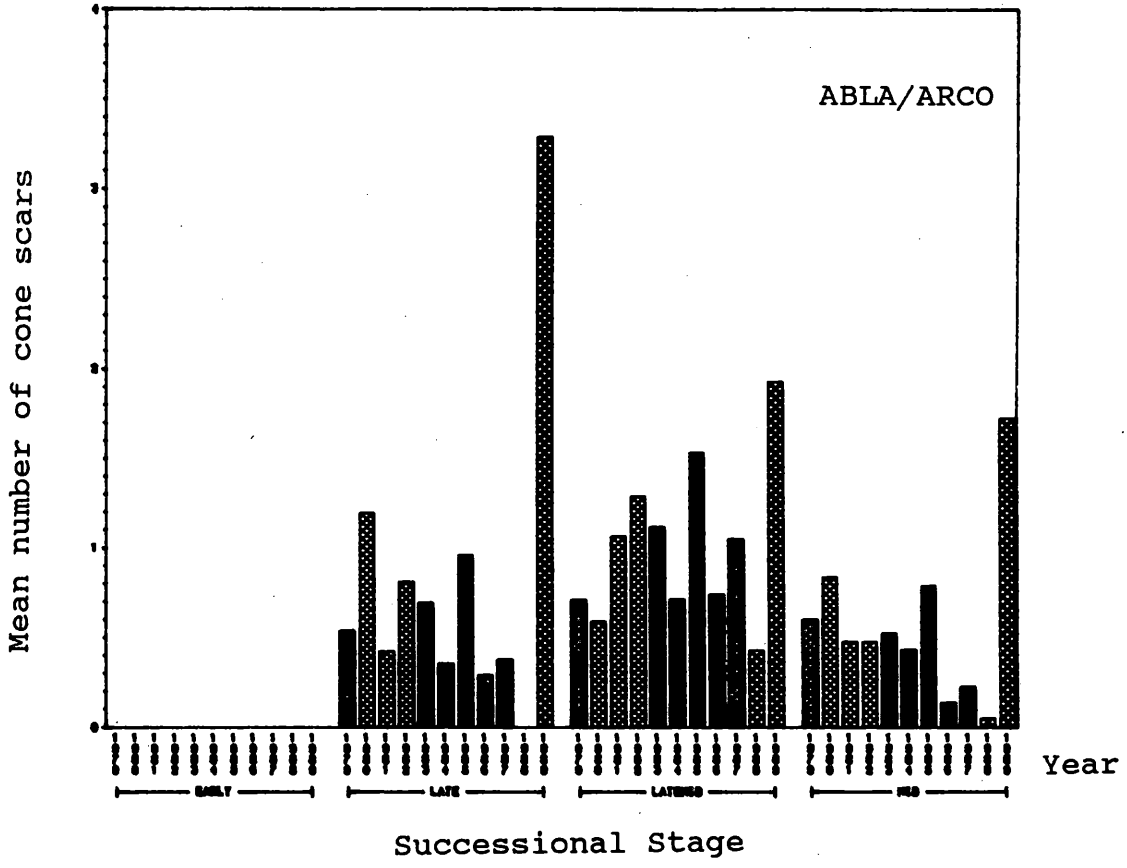






Successional Stage

Fig. 8


ABLA/ARCO
Mean number of cone scars
Year
Successional Stage

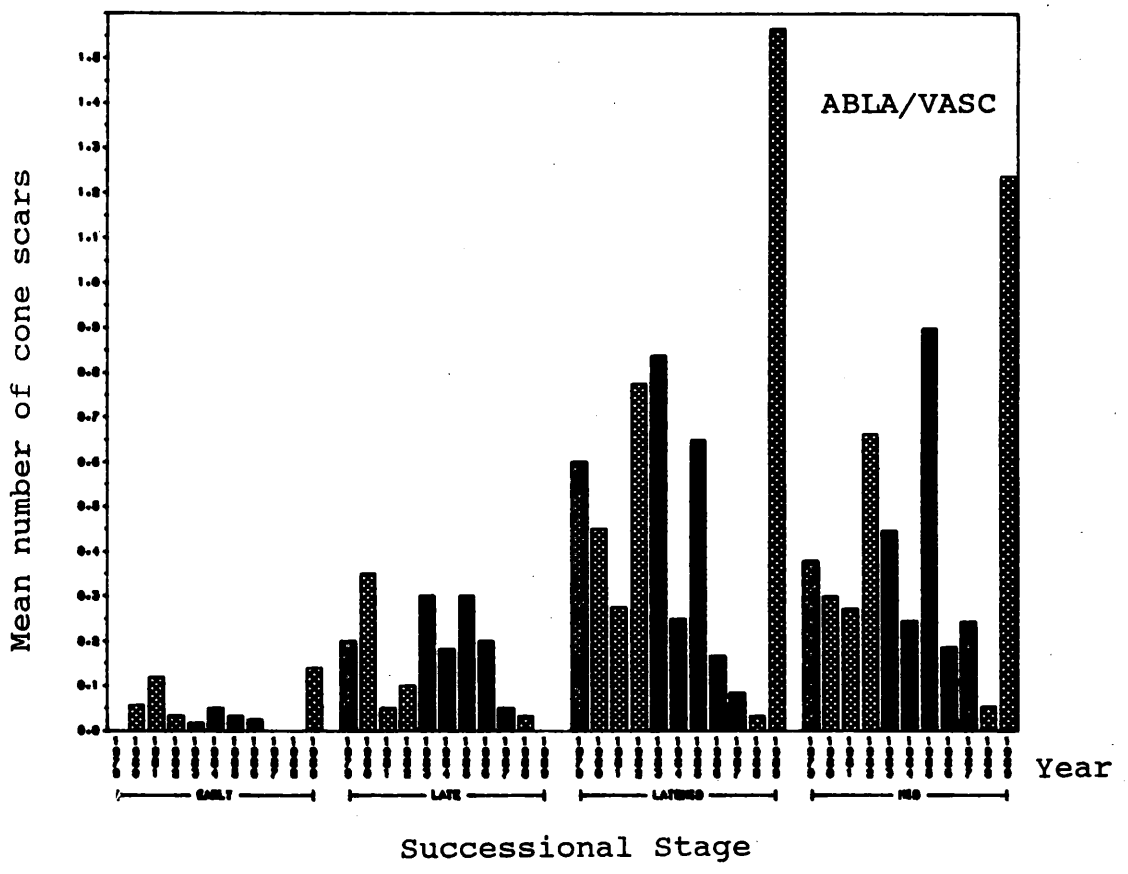

ABLA/VASC
Mean number of cone scars
Year
Successional Stage

Table 3.--Qualitative rating of potential overall fire hazard by habitat type and successional stage. Numbers presented are the percentage of stands sampled within a successional stage for which the fire potential was the same.

Overall Fire Hazard	Early Seral	Mid Seral	Late Mid-Seral	Late Seral
Abies lasiocarpa/ Arnica cordifolia				
Nil	0	17	0	0
Low	100	50	75	25
Medium	0	33	25	50
High	0	0	0	25
Extreme	0	0	0	0
Abies lasiocarpa/ Vaccinium scoparium				
Nil	33	27	0	0
Low	67	45	80	25
Medium	0	27	20	50
High	0	0	0	0
Extreme	0	0	0	25

Table 1.--Ratio of mean sapling density to mean seedling density.

Ratio	Early Seral	Mid Seral	Late Mid-Seral	Late Seral
Abies lasiocarpa/ Arnica cordifolia	0.11	0.05	0.01	0.09
Abies lasiocarpa/ Vaccinium scoparium	0.02	0.07	0.25	0.81

Table 2. Distribution of fire occurrence by season in the Russell Peak area, Shoshone National Forest, Wyoming as determined by the method of Dieterich and Swetnam (1984) where the position of the scar within the growth ring is noted.

Probability that fire caused scars	Season of fire1 Early	Late	Dormant	Number of fires
Highly probable	48%	19%	33%	33
Probable	38%	22%	40%	58

1 Relative to growing season for whitebark pine.

APPENDICES

APPENDIX A.--Fire potential rating by successional stage and habitat type.
APPENDIX B.--Distribution of sampling and seedling and sapling density.
APPENDIX C.--Stand composition (mean basal area, m2/ha) by habitat type and successional stage.

Table A1.--Qualitative rating of potential rate of spread by habitat type and successional stage. Numbers presented are the percentage of stands sampled within a successional stage for which the fire potential was the same.

Rate of Spread	Early Seral	Mid Seral	Late Mid-Seral	Late Seral
Abies lasiocarpa/ Arnica cordifolia				
Nil	0	33	75	25
Low	100	50	80	50
Medium	0	17	25	25
High	0	0	0	0
Extreme	0	0	0	0
Abies lasiocarpa/ Vaccinium scoparium				
Nil	0	27	0	0
Low	83	36	60	25
Medium	17	9	20	75
High	0	27	20	0
Extreme	0	0	0	0

Table A2.--Qualitative rating of torching potential by habitat type and successional stage. Numbers presented are the percentage of stands sampled within a successional stage for which the fire potential was the same.

Torching Potential	Early Seral	Mid Seral	Late Mid-Seral	Late Seral
Abies lasiocarpa/ Arnica cordifolia				
Nil	100	33	0	0
Low	0	50	75	25
Medium	0	17	25	0
High	0	0	0	0
Extreme	0	0	0	0
Abies lasiocarpa/ Vaccinium scoparium				
Nil	100	18	0	0
Low	0	54	60	25
Medium	0	18	20	25
High	0	9	20	50
Extreme	0	0	0	0

Table A3.--Qualitative rating of potential resistance to fire control by habitat type and successional stage. Numbers presented are the percentage of stands sampled within a successional stage for which the fire potential was the same.

Resistance to Fire Control	Early Seral	Mid Seral	Late Mid-Seral	Late Seral
Abies lasiocarpa/ Arnica cordifolia				
Nil	0	17	0	0
Low	100	33	75	0
Medium	0	50	25	50
High	0	0	0	50
Extreme	0	0	0	0
Abies lasiocarpa/ Vaccinium scoparium				
Nil	33	27	20	0
Low	67	54	60	25
Medium	0	18	20	50
High	0	0	0	0
Extreme	0	0	0	25

Table A4.--Qualitative rating of potential fire intensity by habitat type and successional stage. Numbers presented are the percentage of stands sampled within a successional stage for which the fire potential was the same.

Intensity	Early Seral	Mid Seral	Late Mid-Seral	Late Seral
Abies lasiocarpa/ Arnica cordifolia				
Nil	0	17	0	0
Low	100	67	50	50
Medium	0	17	50	0
High	0	0	0	50
Extreme	0	0	0	0
Abies lasiocarpa/ Vaccinium scoparium				
Nil	50	27	20	0
Low	50	45	40	25
Medium	0	18	40	50
High	0	9	0	0
Extreme	0	0	0	25

Table A5.--Qualitative rating of crowning potential by habitat type and successional stage. Numbers presented are the percentage of stands sampled within a successional stage for which the fire potential was the same.

Crowning Potential	Early Seral	Mid Seral	Late Mid-Seral	Late Seral
Abies lasiocarpa/ Arnica cordifolia				
Nil	100	17	0	0
Low	0	83	75	50
Medium	0	0	25	0
High	0	0	0	50
Extreme	0	0	0	0
Abies lasiocarpa/ Vaccinium scoparium				
Nil	100	27	0	0
Low	0	63	60	25
Medium	0	9	20	0
High	0	0	0	50
Extreme	0	0	20	25

Table A6.--Qualitative rating of potential overall fire hazard by habitat type and successional stage. Numbers presented are the percentage of stands sampled within a successional stage for which the fire potential was the same.

Overall Fire Hazard	Early Seral	Mid Seral	Late Mid-Seral	Late Seral
Abies lasiocarpa/ Arnica cordifolia				
Nil	0	17	0	0
Low	100	50	75	25
Medium	0	33	25	50
High	0	0	0	25
Extreme	0	0	0	0
Abies lasiocarpa/ Vaccinium scoparium				
Nil	33	27	0	0
Low	67	45	80	25
Medium	0	27	20	50
High	0	0	0	0
Extreme	0	0	0	25

Table B1.--Number of stands sampled by habitat type and successional stage.

Habitat Type	Early Seral	Mid Seral	Late Mid-Seral	Late Seral
Abies lasiocarpa/ Arnica cordifolia	1	8	7	4
Abies lasiocarpa/ Vaccinium scoparium	7	12	4	5

Table B2.--Mean seedling and sapling densities (#/ha)

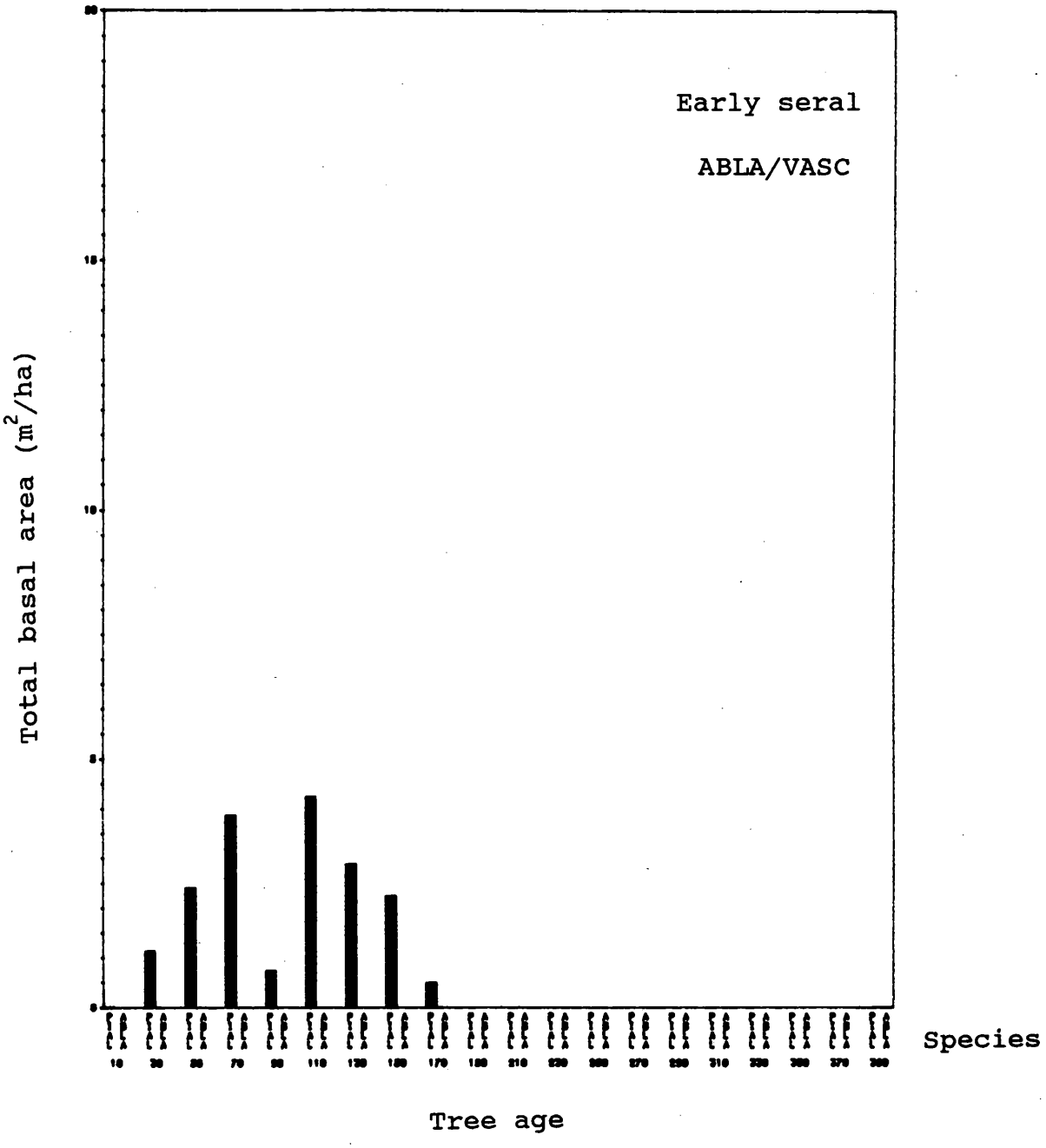
	Early Seral	Mid Seral	Late Mid-Seral	Late Seral
Abies lasiocarpa/ Arnica cordifolia				
Seedling Density	6.0	33.3	45.8	5.7
Sapling Density	0.7	1.6	0.5	0.5
Abies lasiocarpa/ Vaccinium scoparium				
Seedling Density	18.1	27.0	11.0	10.3
Sapling Density	0.4	1.9	2.7	8.3

Figure C1.--Stand composition (mean basal area, m^2/ha) for early seral stands on the Abies lasiocarpa/Vaccinium scoparium (ABLA/VASC) habitat type.

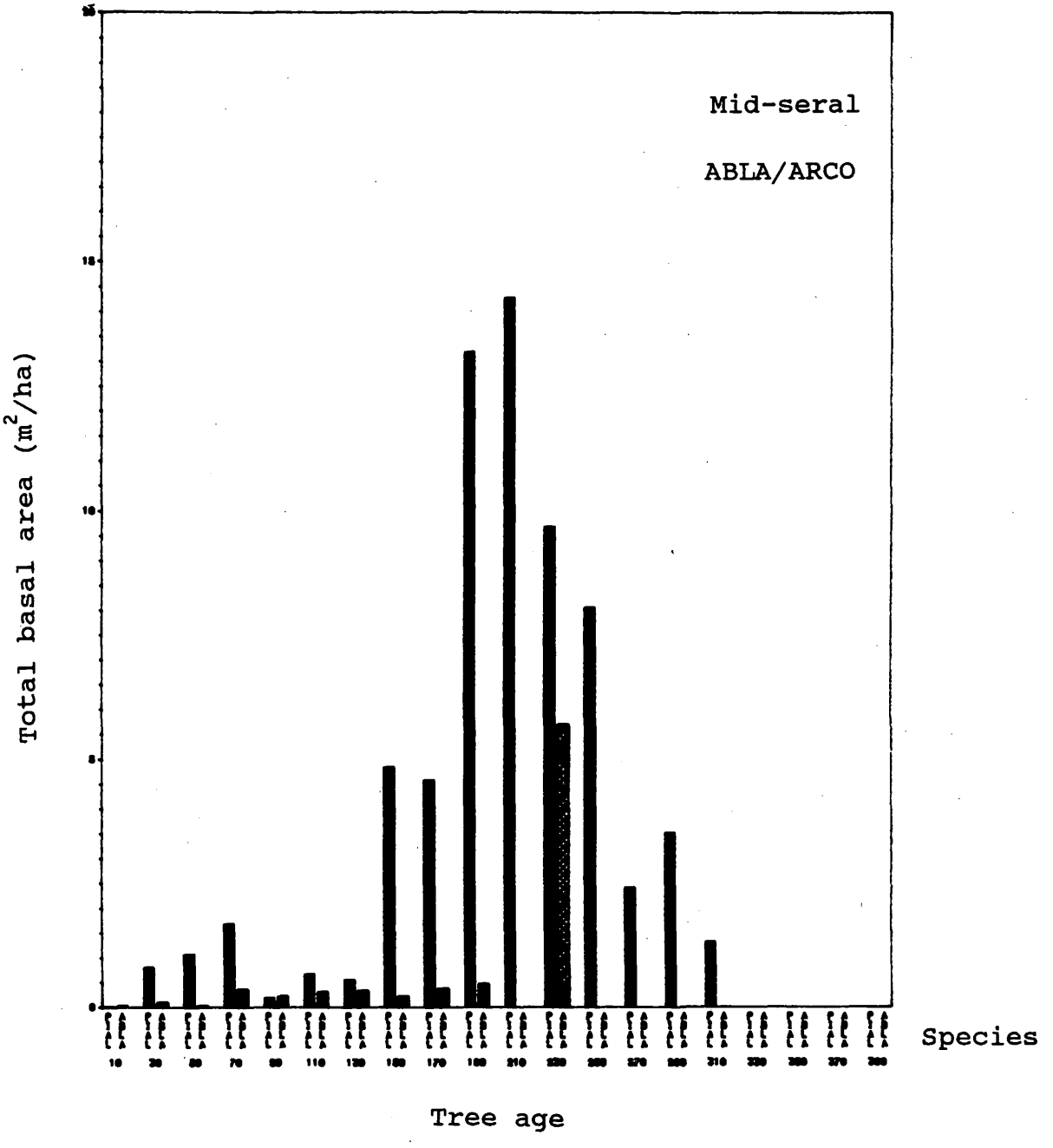
Figure C2.--Stand composition (mean basal area, m^2/hanumber stems/ha) for mid-seral stands on the Abies lasiocarpa/Arnica cordifolia (ABLA/ARCO) and Abies lasiocarpa/Vaccinium scoparium (ABLA/VASC) habitat types.

Figure C3.--Stand composition (mean basal area, m^2/ha) for late mid-seral stands on the Abies lasiocarpa/Arnica cordifolia (ABLA/ARCO) and Abies lasiocarpa/Vaccinium scoparium (ABLA/VASC) habitat types.

Figure C4.--Stand composition mean basal area, m^2/ha) for late seral stands on the Abies lasiocarpa/Arnica cordifolia (ABLA/ARC)O and Abies lasiocarpa/Vaccinium scoparium (ABLA/VASC) habitat types.


Early seral
ABLA/VASC
Total basal area (m^2/ha)
Species
Tree age

9 C2



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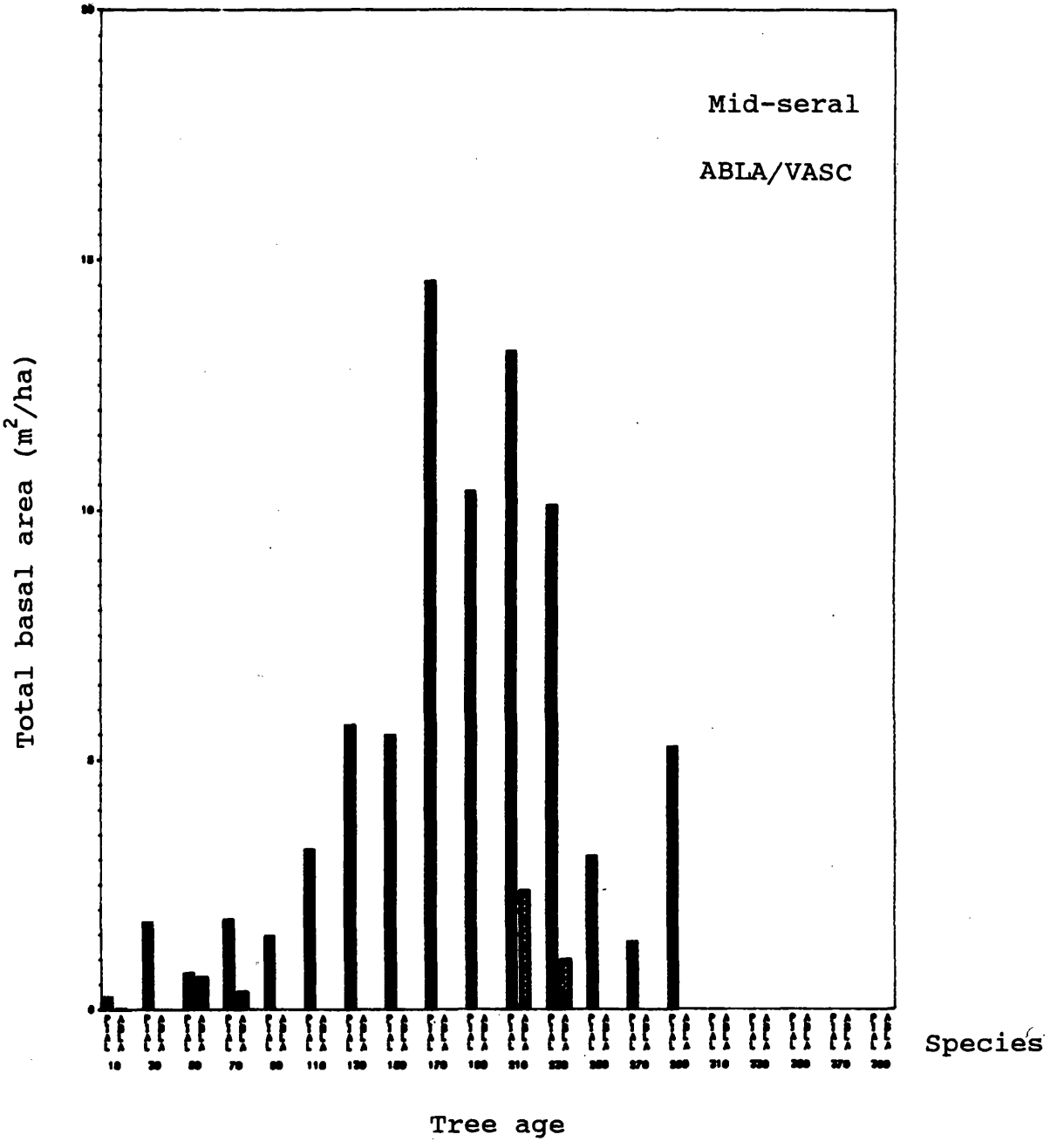

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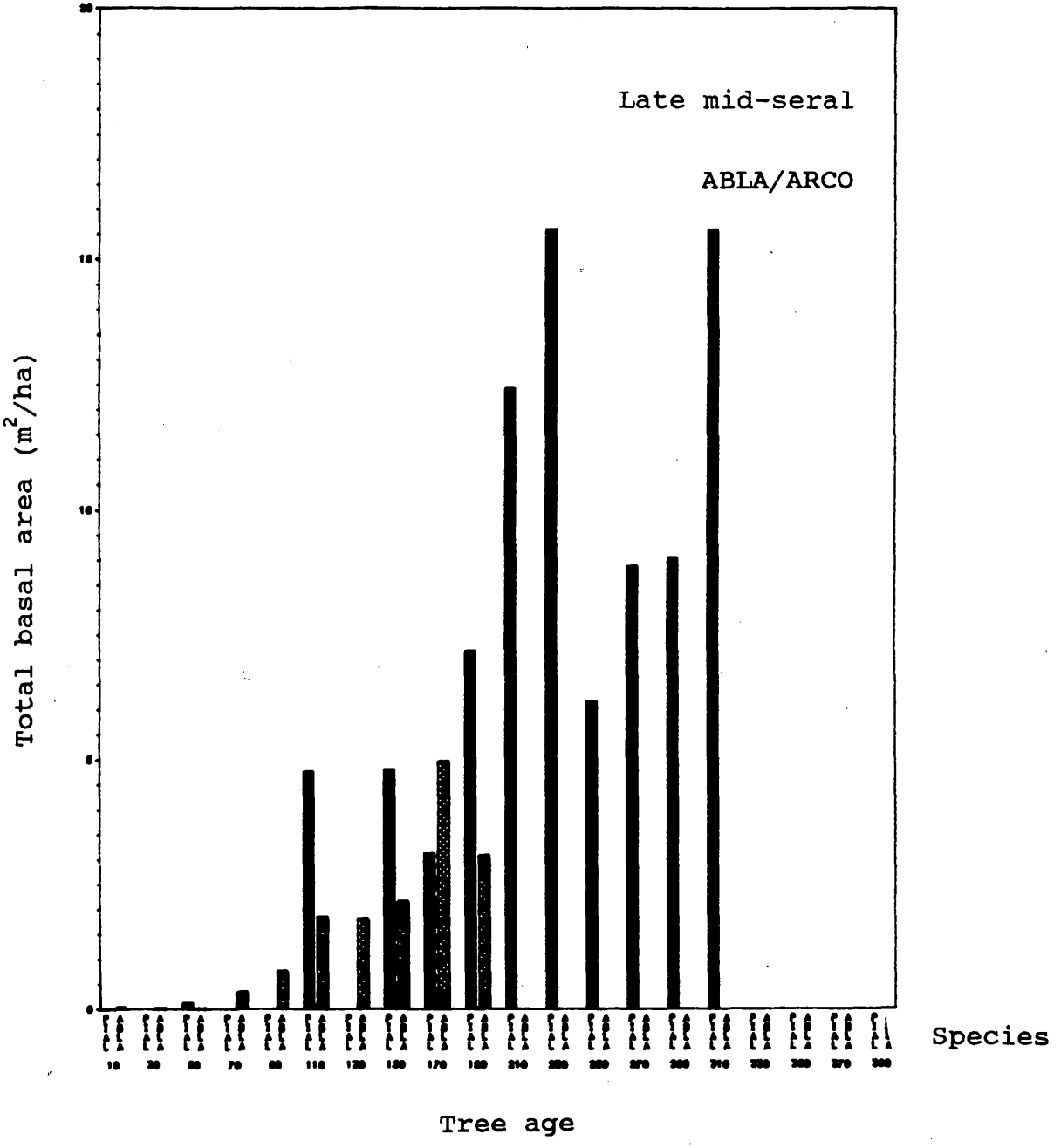

Late mid-seral
ABLA/ARCO
Total basal area (m²/ha)
Species
Tree age

C3

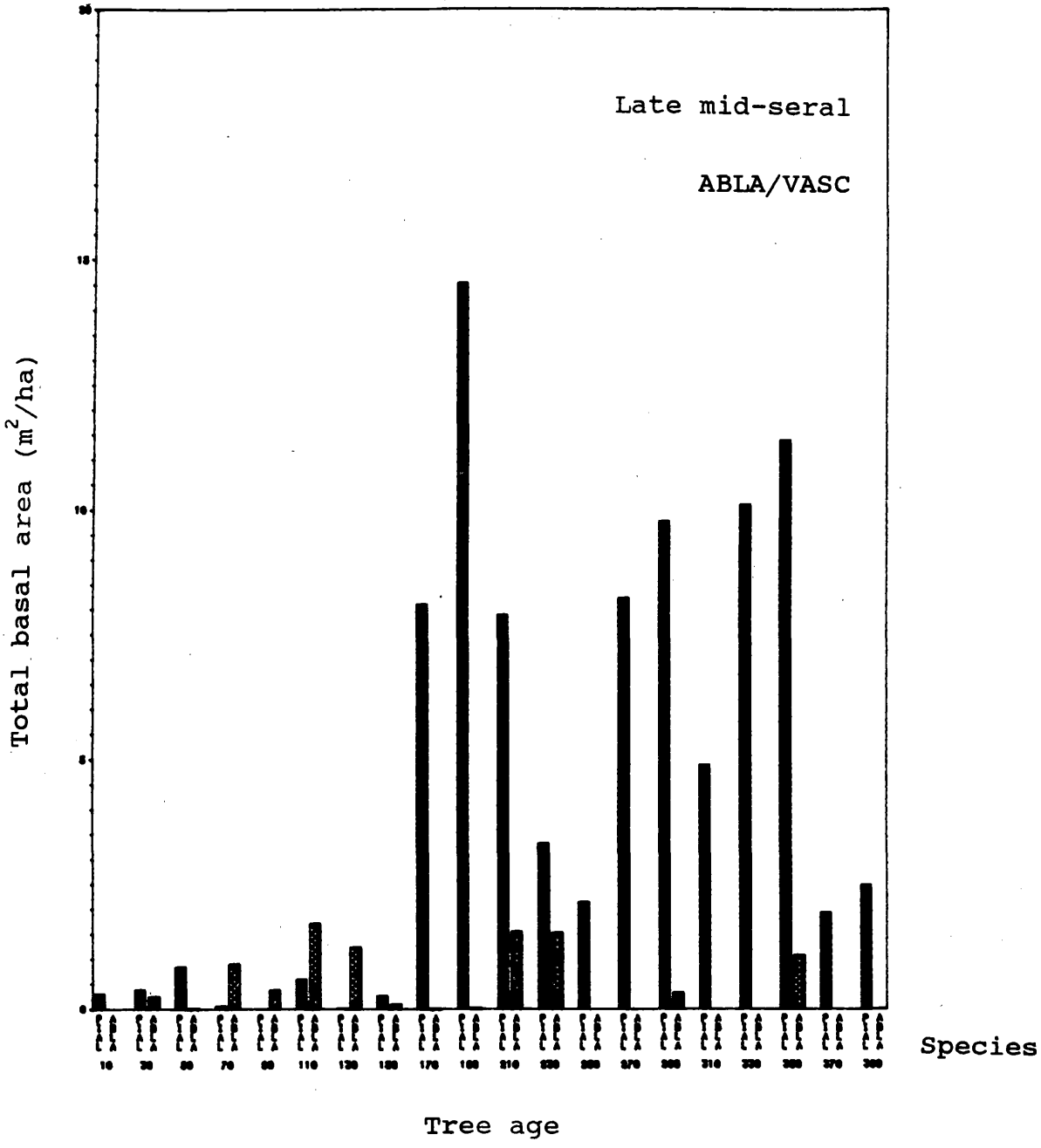
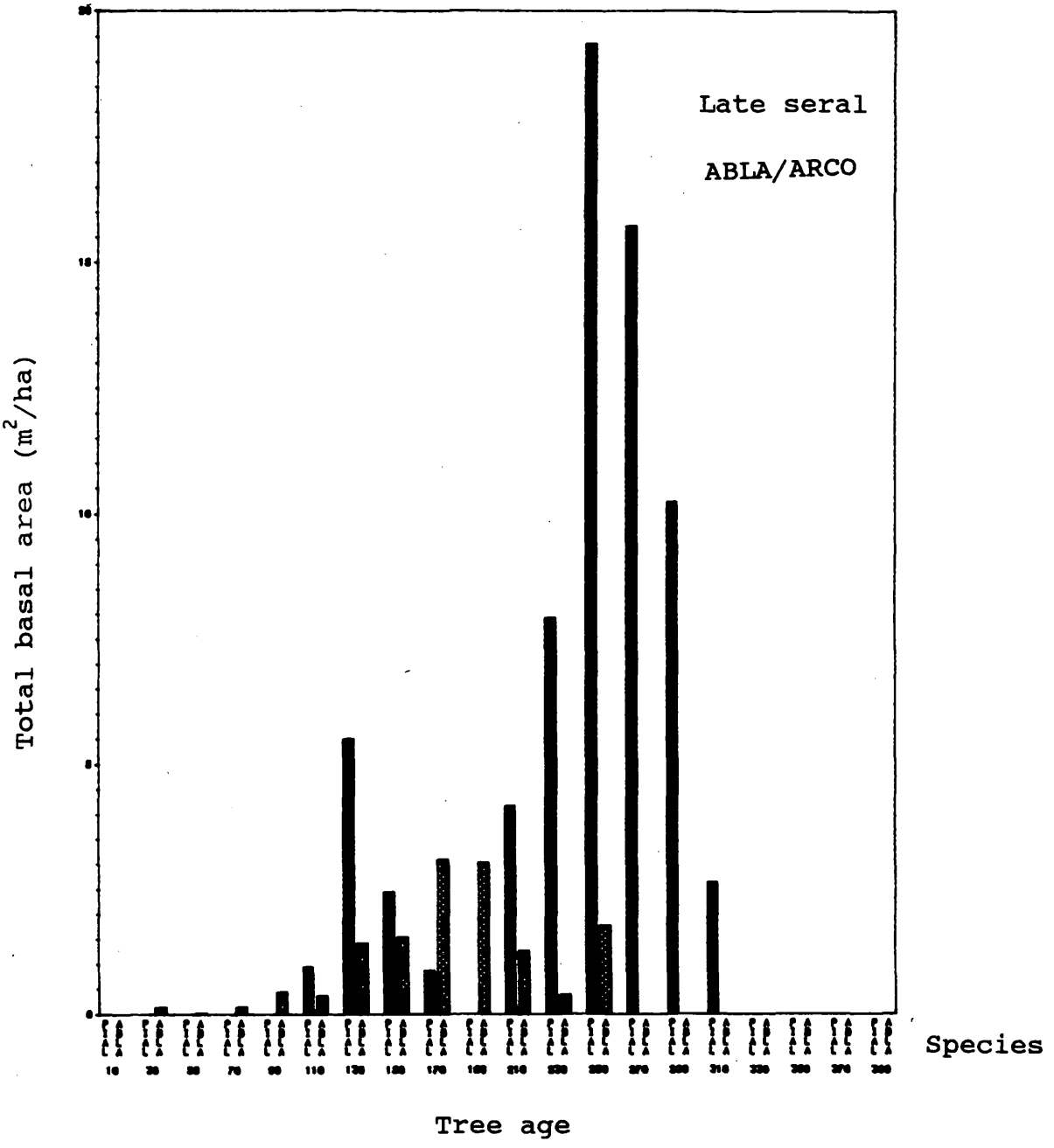
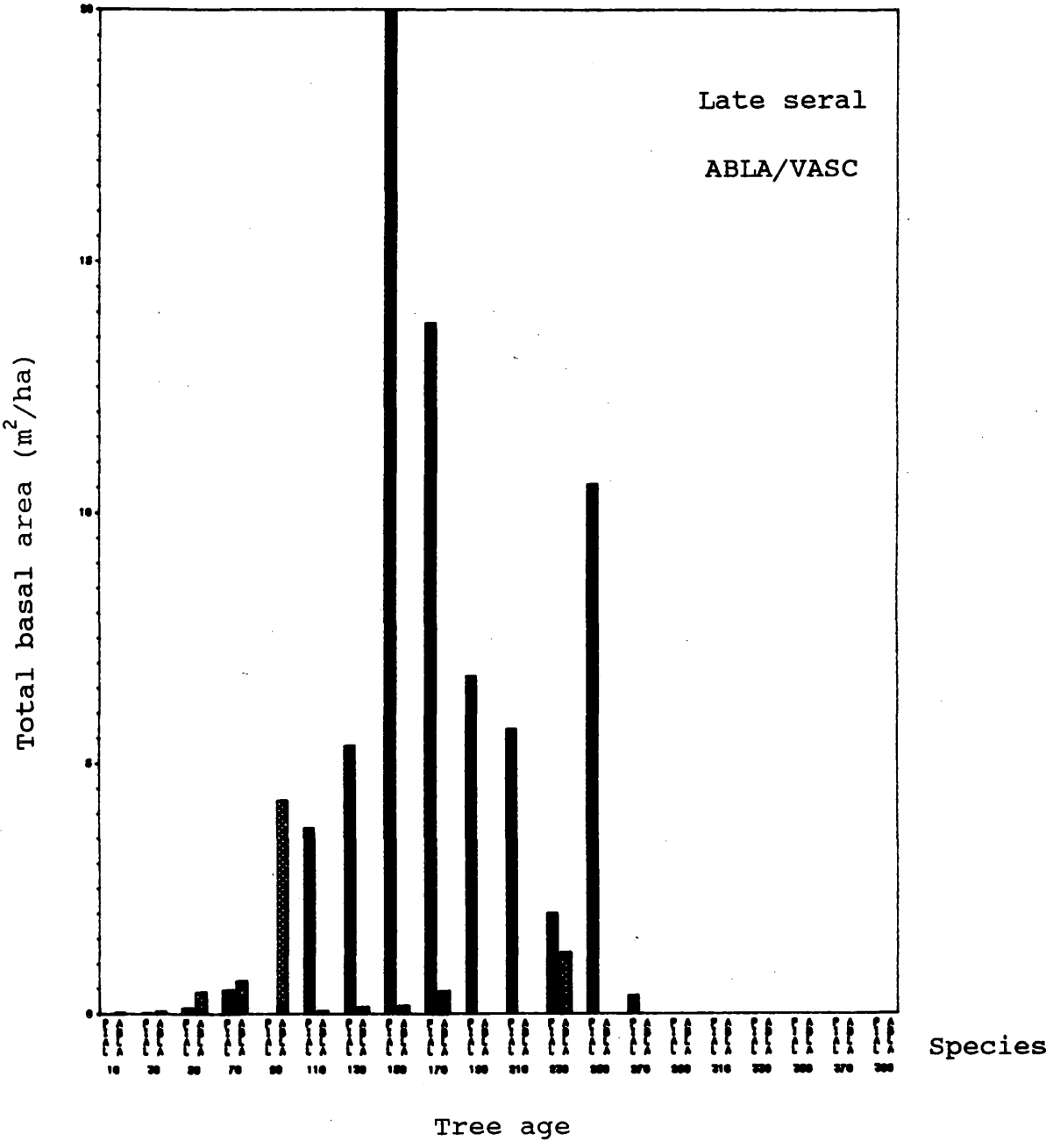

Late mid-seral
ABLA/VASC
Total basal area (m²/ha)
0
5
10
15
Species
Tree age

Fig 4




Late seral
ABLA/VASC
Total basal area (m²/ha)
Species
Tree age